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THE CONDUCTIVITY AND DISSOCIATION OF ORGANIC ACIDS IN AQUEOUS SOLUTION AT DIFFERENT TEMPERATURES.

DISSERTATION

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By

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The Conductivity and Dissociation of Organic Acids in Aqueous Solution at Different Temperatures.

A thoroughly systematic study of the conductivity and dissociation of organic acids, as affected by temperature as well as by dilution, has not been made since this important method of determining the strength of electrolytes has been devised. There are a few articles in the literature which deal with the subject, but a comprehensive investigation in this field is lacking, and many of the conclusions that have been reached are conflicting. In the review presented here of work dealing with the conductivity and dissociation at various temperatures, attention will be called chiefly to matter dealing with the subject in hand; that is, the organic acids.

It was early observed that the conductivity of electrolytes in solution changes with the temperature, and in the reverse sense to that of metals. This fact was long known without accurate or extended measurements having been made to further our knowledge of the subject. Over sixty years ago Ohm(1) and Becquerel(2) pointed out a few facts concerning the effect of temperature on conductivity. Hankel(3), in a piece of work of wider scope than any preceding it, showed that the electrical resistance of many solutions very noticeably de-

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1. Pogg. Ann., 63, 403 (1844).
2. Ibid., 70, 254 (1847).
3. Ibid., 69, 255 (1846).

creased with rising temperature, and he worked out a few general relations connecting the behavior of various electrolytes. E. Becker(1) in 1850 studied the conductivity of solutions of a few of the common acids and salts between 0° and 100°, formulating some of his results in aquations connecting temperature and conductivity. Attention may also be called to the work of Beetz(2), Freund(3), Bergren(4), and Long(5).

The first serious and important investigation was completed in 1874 by Grotrian(6) who studied the conductivity of solutions of hydrochloric acid and sulphuric acid, use being made of the alternating current method of Kohlrausch. Giotrian found that the conductivity of the hydrochloric acid solution was a linear function of the temperature between 0° and 33°, but he obtained a parabolic interpolation formula for the sulphuric acid between 0° and 70°. A maximum in conductivity occurred at a definite dilution, which, in the case of sulphuric acid, became greater the higher the temperature. The solution of hydrochloric acid behaved in the opposite way. This work was followed by that of Kohlrausch and Grotrian(7), in which were investigated many electrolytes, including nitric acid and some alkali and alkaline earth salts. They concluded that it is a practically general truth that in dilute solutions conductivity is a parabolic function of the temperature. They applied the ordinary equation of the parabola,-

$$K_t = K_o(1 + \alpha t + \beta t^2),$$

in which α and β are constants depending on the nature of the elec-

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1. Ann. Chem. (Liebig), 73, 1 (1850).
2. Pogg. Ann., 117, 1 (1862).
3. Wied. Ann., 7, 49 (1879).
4. Ibid., 1, 499 (1877).
5. Ibid., 11, 37 (1880).
6. Pogg. Ann., 151, 378 (1874).
7. Ibid., 154, 215 (1875).

trolyte, and easily calculated, and K_t and K_o are the conductivities at t° and 0° respectively. Kohlrausch(1) then obtained the first reliable data on the conductivity of solutions of organic acids. These included acetic, oxalic and tartaric acids. As in the previous work, maxima in conductivity were obtained when measurements were made of solutions varying in composition from nearly pure acid to pure water. The maximum conductivities of the mineral acids were much higher than the values found for the organic acids.

Nothing of importance came from the work of Bouty(2), on the conductivity of organic acids. He found that they are very poor conductors, the best conducting having a resistance 50 - 200 times as great as that of neutral salts.

In 1877 Otten(3) studied the influence of temperature on the conductivity of some fatty acids. He used formic, acetic, propionic and butyric acids, and showed that the resistance increases as we ascend in the homologous series. In the case of all the acids the conductivity increased with the percentage content of the solution up to a maximum and then decreased. The maximum for formic acid existed at a concentration of about 30 per cent, and for the higher members in the series it occurred at a lower concentration.

When we come to Ostwald's electrochemical studies we meet with work of the greatest importance in this field; his contributions being of considerable theoretical value, while his experimental data are very elaborate. In 1884(4) he introduced the conception of the "affinity" of an acid, this being a character-

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1. Pogg. Ann., 159, 233 (1876).
2. Compt. rend., 99, 30.
3. Diss., München (1887).
4. J. pr. Chem., 30, 93, (1884).

istic property which influences its rate of chemical reaction and also its conductivity. That the latter are proportional he showed by a comparison of the relative conductivities of many organic acids and their affinities, as measured by their influence on the rate of formation of methyl acetate and the inversion of cane sugar. In a later paper(1) Ostwald derived some important relations between dilution and conductivity. Molecular conductivities were calculated. The dilutions varied as whole powers of two, and were obtained by removing one half the volume of solution from the electrolytic cell, and replacing it by pure water. The decrease in conductivity of mineral acids, after the maximum was reached, was observed and ascribed to impurities in the solvent, which become noticeable at higher dilutions. The conductivities of organic acids advanced along strictly parallel lines, but no maxima were attained.

In an elaborate study(2) of the electrical conductivity of organic acids, Ostwald showed the effect of constitution on the conductivity, but his later work covers the same ground and is more reliable, so that reference only need be made to these early investigations.

At this time Ostwald had come to the conclusion that the molecular conductivity of monobasic acids increases with dilution up to a maximum, which should prove to be the same for all acids. In 1887(3) he disproved this theory, finding a variation as great as 12 per cent in the case of many acids. The maximum value for acids of low conductivity, however, could not be obtained directly, and a study was made of the relation between the conductivity of several organic acids and that of their alkali salts; this work

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1. J. pr. Chem., [2], 31, 433 (1885).
2. Ibid., [2], 32, 300 (1886).
3. Z. physik. Chem., 1, 74, 97 (1887).

being suggested presumably by Kohlrausch's law of the independent migration of ions. It was found that a constant difference existed between the two at equal dilutions, and, therefore, the conductivity of an acid may be represented by the conductivity of one of its salts plus a constant. It was also found that the molecular conductivity of the sodium salts of monobasic acids increases from dilution 32 - 1024 liters by the constant amount of 10 - 13 units. Double this change was obtained with dibasic acids, so that a method was at hand for the determination of the basicity of an acid. The principle was also made use of later for calculating the conductivity at infinite dilution of organic acids. In an article(1) bearing upon the relation between composition of ions and their speed of migration, ionic velocities were calculated in the following manner. μ_∞, for a sodium salt, was obtained from its conductivity at a certain dilution, by adding to this value the difference between the conductivity of sodium chloride at this dilution and that at infinite dilution as obtained by Kohlrausch. This method, of course, is allowable in the light of the fact above mentioned, that the difference between the conductivities of a sodium salt at two dilutions equals the difference between the values of any other sodium salt at those same dilutions. Ostwald considered this method of calculating μ_∞ for the salts preferable to a direct determination, although the latter is very simple, as the author of the present article will show. Hittorf's values for the relative velocities of the ions in sodium chloride solutions gave constants for the sodium ion which enabled Ostwald to calculate the migration velocities of a number of organic anions from the conductivity of their sodium salts. It was observed that in homologous series, the

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1. Z. physik. Chem., 2, 840 (1888).

velocity of the anion decreased with increasing molecular weight. The influence exerted by substituting various elements in the anion, upon its velocity was also noted; this influence being least when the molecular weight is large. Ostwald worked out a method for calculating anion velocities, and, consequently, μ_α for organic acids, when there are over twelve atoms in the anion. When this latter is the case, the velocity of the anion depends only on the number of atoms, so that a curve may be drawn with the number of atoms as abscissae, and velocities as ordinates. The curve obtained was convex toward the abscissa, approaching it assymptotically.

Making use of some of the above observations connecting the conductivity of acids with their basicity and anion velocity, Ostwald(1) proved isomalic acid to be identical with citric acid.

To obtain a correct idea of the scope and the results of Ostwald's important work on the affinity constants of organic acids at 25°, the original article(2) should be consulted. His observations on the relations between these constants and the chemical composition, constitution and configuration of the acids, have been of the greatest service to workers in this field since the appearance of this paper. The value of k, calculated from the dilution law(3), generally remained constant, decreasing only at high dilutions where the effect of impurities becomes large. In a few instances the constant increased in value, due to decomposition of the solutions when in contact with the platinum electrodes; and in the case of the amino benzoic acids to other causes to be mentioned later in this paper. The values of the constants serve to characterize struc-

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1. Ber. d. chem. Ges., 21, 3534 (1888).
2. Z. physik. Chem., 3, 170, 241, 369 (1889).
3. Ibid., 2, 36, (1888).

tural and geometrical isomers; its value for unknown acids could be predicted with considerable certainty.

Reference(1) only, will be made to the numerous investigations carried out since the publication of Ostwald's papers on the conductivity of organic acids at one temperature as the results generally are only characteristic ofthe particular acids worked with, and do not bear directly on the subject of this present article.

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1. Hartwig: Wied. Ann., 33, 58 (1888).
Berthellot: Compt. rend., 110 , 703;
Ibid., 112, 46, 287, 335.
Ibid., 113, 21.
Bischoff and Walden: Ber. d. chem. Ges., 23, 1950 (1890).
Walden: Z. physik. Chem., 8, 433 (1891).
Ibid., 10, 563 (1892).
Bader: Ibid., 6, 289 (1890).
Bethmann: Ibid., 5, 385 (1890).
Walker: J. Chem. Soc., Trans., 61, 696 (1892).
Ebersbach: Z physik. Chem., 11, 608 (1893).
Lovén: Ibid., 13, 550 (1894).
Wegscheider: Monatsh., 16, 153 (1895).
Ibid., 23, 287, 317, 357 (1902).
Franke: Z. physik. Chem., 16, 463 (1895).
Szyzkowski: Ibid., 22, 173 (1897).
Ruff: Ber. d. chem. Ges., 32, 550 (1899).
Von Schilling und Vorläuder: Ann. Chem. (Liebig), 308, 184 (1899).
Billitzer: Monatsh., 20, 666 (1889).
Roth: Ber. d. chem. Ges., 33, 2032 (1900).
Lichtig: Ann. Chem. (Liebig), 319, 369 (1902).

The conductivity of various electrolytes was measured in dilute solutions by Arrhenius(1) at 18° and 52°, and by means of the formula

$$\mu_{52} = \mu_{18}(1 + \alpha_{35}\cdot 34)$$

in which μ is the molecular conductivity and α the temperature coefficient, he was able to calculate the mean temperature coefficient between these temperatures. The temperature coefficients of the more strongly dissociated electrolytes are generally smaller the greater the conductivity; hence, the conductivities approach one another as the temperature rises. The change of the coefficients with the strength of the solution is not great so long as the latter remains small. Arrhenius also observed an exceedingly important fact, viz., that the dissociation of phosphoric acid and hypophosphorous acids decreases with rise in temperature. This was a surprizing discovery in the light of the old theory, which explained increase in conductivity with rise in temperature on the assumption of increase in dissociation. This question of the influence of temperature on dissociation has remained a subject of study up to the present day, and still needs a large amount of further investigation.

The work of Krannhals(2) may be mentioned here. He discovered few new relations in his study of the conductivity of some typical acids and salts, and his results generally confirmed the conclusions of Kohlrausch and Grotian. He concluded that temperature has no effect on dissociation.

In 1895 Jahn and Schröder(3) made determinations of the conductivity of aqueous solutions of formic, acetic, propionic,

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1. Z. physik. Chem., 4, 96 (1889).
2. Ibid., 5, 250 (1890).
3. Ibid., 16, 72 (1895).

butyric, isobutyric, and valeric acids. Each acid was investigated in solutions varying from N/2 to N/128, and at a series of temperatures ranging from 10° to 50°. They expressed their results by interpolation formulae, calculated values agreeing satisfactorily with those observed. Their method of work was not sufficiently accurate to enable them to notice a change in dissociation with temperature, and they infer, therefore, that it is constant. Their results, however, show a decreasing dissociation with rise in temperature in the case of valeric acid, but they assumed this to be due to the presence of impurities. Jahn therefore concluded that increase in conductivity with the temperature is a function of the decrease of ionic friction. Deguisne(1) and Wood(2) also worked in the field at this time.

In 1896 Euler(3) studied some typical aromatic organic acids between 10° and 50° and at various dilutions. The acids were benzoic, o-toluic, salicylic, m-oxybenzoic and m-nitrobenzoic. Interpolation formulae were calculated for each acid at every dilution, and were found to be of the form

$$\lambda = a + bt + ct^2,$$

where λ represents the molecular conductivity and t the temperature. The form of the equation indicates a maximum in the curve, if the expression applies at higher temperatures. In every case the dissociation varied with the temperature, a maximum occurring for benzoic acid at about 35°, and for m-oxybenzoic acid at about 28°. The values for toluic acid decreased with rising temperature, but those for m-nitrobenzoic and salicylic acids increased. Euler offered no explanation for these inharmonious results, and further investiga-

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1. Diss., Strassbourg (1895).
2. Phil. Mag., 41, 117 (1896).
3. Z. physik. Chem., 21, 257 (1896).

tion of this subject seems necessary before the work could be accepted as final. There is no apparent reason why m-oxybenzoic acid and salicylic acid should differ so markedly in their behavior, and the other relations seem inconsistent.

Schaller(1) studied the conductivity of several acids, bases and salts, including a few organic acids. He made use of platinum vessels to avoid the solvent action of water on glass at the higher temperatures at which he worked. The molecular conductivities were found to increase with rise in temperature, but at a diminishing rate, so that in some cases a maximum was reached, beyond which the molecular conductivity decreased. The degree of dissociation, however, in all cases decreased with rise in temperature, when the latter was above 25°. The value for the dissociation at 25° was usually less than that at the next higher temperature worked.

In 1901 Jones and Douglas(2) measured the conductivity of a number of inorganic acids, bases and salts between 0° and 35°. They observed that for salts the temperature coefficients increase with rise in temperature, but noticed little change for acids and bases. Their results showed that temperature affects dissociation to no appreciable extent.

The work of Jones and West(3) and of Jones and Jacobson(4) at temperatures varying from 0° to 35°, and of Noyes(5) at higher temperatures, has established conclusively that dissociation decreases with rise in temperature for most of the substances they investigated. Jacobson obtained this result with a few organic acids

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1. Z. physik. Chem., 25, 497 (1898).
2. This Journal, 26, 428 (1901).
3. Ibid., 34, 357 (1905).
4. Ibid., 40, 355 (1908).
5. J. Am. Chem. Soc., 26, 134 (1904).

but found an increasing dissociation with rising temperature in the case of m-nitrobenzoic acid and a few inorganic salts. He suggests that this was due to the influence of hydrolysis. He showed, further, that molecular conductivity is in general (water being a marked exception) a parabolic function of the temperature(1), a state of things which may be explained by the theory of hydration which Jones has put forward as a result of considerable work by himself and students. According to this theory, it appears that all electrolytes in aqueous solution are more or less hydrated, a condition which would prevent conductivity from being a linear function of the temperature; as it very probably would be if the viscosity of the medium alone were the influencing factor. Jones sums up the facts now known in a recent paper(2) to which attention is here called.

Recently Jones and Clover(3) have studied the conductivity of a few organic acids at temperatures ranging from 35° to 65°, but without measuring their dissociation.

From what has been said of the work already done, it is evident that more accurate and more extended data on the conductivity of organic acids, as affected by temperature, should be obtained. It is intended in this article to supply in part this deficiency for a number of typical acids of both the aliphatic and aromatic series.

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1. This Journal 40, 402 (1908).
2. Ibid., 41, 19 (1909).
3. Ibid., 43, 187 (1910).

EXPERIMENTAL PART.

The measurements were carried out by means of the ordinary Kohlrausch method with a Wheatstone bridge, rheostat, induction coil and telephone receiver. The bridge wire and thermometers were calibrated carefully, the latter to within 0°.01. All flasks, burettes andpipettes were calibrated for 20°. The conductivity cells were of the type used by Jones and Bingham(1) and which have given satisfactory results in this laboratory for several years.

The measurements were made at four temperatures ranging from 0° to 35°, and at various dilutions from N/2 up to N/2048, or as near the former concentration as possible, this being dependent on the solubility of the acid.

The 0° bath was that made use of by Jones and Jacobson(2), and fully described in their article bearing on this same subject. The cells containing the solutions which it was desired to bring to a temperature between 0° and 25°, were placed in a tank through which tap water was kept flowing and stirred by its own pressure. Satisfactory results were obtained by this method, no measurements being taken until the temperature was observed to be constant within 0°.02 for at least half an hour. During the latter part of the work this bath was kept at 12° by running the water in at constant pressure and heating at the same time with a burner.

The 25° and 35° baths were heated by Bunsen burners. No automatic regulator was used, the size of the flame being easily regulated by a pinchcock, so that the maximum variation in temperature was no greater than 0°.02. The baths were stirred by paddles

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1. This Journal 34, 481 (1905).
2. Ibid., 40, 355 (1908).

rotated by hot-air engines.

It was necessary for the cells to remain for at least an hour in those baths kept at and below a temperature of 25°. At 35°, however, the solutions gave constant readings in the short space of half an hour. Duplicate readings were taken after an interval of five minutes to insure constant temperature. The final results also were the average of three measurements, taken with the minimum as near the center of the bridge as convenient. As few plugs as possible were removed from the resistance box.

Cell Constants.--The cell constants were obtained in the usual manner, by the aid of a N/50 solution of pure potassium chloride. Kohlrausch's value for the molecular conductivity of this solution is 129.7 (Siemen's units); adding to this the amount due to the conductivity of the water, the constants can be easily calculated. For those cells in which the platinum plates were close together a N/500 solution of potassium chloride was used, the conductivity of which was measured in the cells standardized with the N/50 solution. The constants were redetermined frequently, although absolutely no change, within the limits of experimental error, was found in many for several months. With due caution as to removing the electrodes from the cell cups this result is easily obtainable, and more reliance can be placed on the measurements. At the temperatures at which we worked there was no noticeable effect on the conductivity due to the solubility of the glass in the solvent.

Water.--The conductivity water employed in making up the solutions was distilled according to the method previously used in this laboratory and frequently described. The process consists simply in the distillation of ordinary distilled water from a potassium bichromate solution, acidified with sulphuric acid to destroy organic matter and retain ammonia. The distillate is then

distilled from a flask containing barium hydroxide, and finally redistilled through a block tin condenser; the last two operations being carried out in one piece of apparatus. The water thus obtained had a conductivity at 25° varying from 1.2×10^{-6} to 1.7×10^{-6}. It was kept in glass bottles long used for the purpose, and withdrawn by a siphon and protected from carbon dioxide in the air by soda-lime.

Organic Acids.--The organic acids in most instances were obtained from Kahlbaum. They were purified by crystallization or distillation, as was most suitable, and tested as to their purity by their melting points or boiling points. The liquid acids were made up into solutions which were standardized by potassium hydroxide dissolved in absolute alcohol, phenolphthalein being employed as the indicator. As the acid was dissolved in conductivity water the absence of carbonic acid was assured, and the titration made reliable. The most concentrated solution being brought to the desired normality, the more dilute solutions were made up from this. The solutions of the solid acids were obtained in the same manner, the mother solution being made up by weight and standardized by titration.

μ_∞ for Sodium Chloride.--In order to obtain μ_∞ for the organic acids to calculate their dissociation, the method which involves the use of the sodium salts of these acids, based on Kohlrausch's law of the independent migration of ions, was resorted to. Thus to calculate μ_∞ for acetic acid for instance, the following equation suffices,

$$\mu_\infty(\mathrm{H\ Ac}) = \mu_\infty(\mathrm{HCl}) + \mu_\infty(\mathrm{NaAc}) - \mu_\infty(\mathrm{NaCl}),$$

in which μ_∞ is the limiting conductivity for each substance. The following table gives the conductivity of sodium chloride solu-

tions between 0° and 35°.

Sodium Chloride

v.	μ_v 0°	μ_v 12°.13	μ_v 25°	μ_v 35°
32	57.17	79.69	106.2	128.6
128	59.76	83.96	112.3	137.2
512	62.01	87.54	117.0	142.1
1024	62.80	88.58	118.4	143.7
2048	*63.04	88.98	*118.8	*144.0

The following equation was calculated by means of values marked with an asterisk in the table.

$$\mu_\infty = 63.04 + 2.04t - 0.00823t^2.$$

μ_{2048} calculated at 12°.13 from this equation gave 88.99, while that observed was 88.98.

μ_∞ for Hydrochloric Acid.--Following is a table which served to give the limiting conductivities of hydrochloric acid.

Hydrochloric Acid.

v.	μ_v 0°	μ_v 14°.82	μ_v 25°	μ_v 35°
128	240.7	326.6	384.9	438.0
512	245.4	332.3	392.0	448.0
1024	243.0	331.0	387.1	444.7

The maximum conductivity was taken as μ_∞, and varies according to the following equation,

$$\mu_\infty = 245.4 + 6.06t - 0.00776t^2.$$

μ_{512} calculated at 14°.82 gave 331.1 as against 331.0 observed.

μ_∞ for the Sodium Salts of the Organic Acids.--Ostwald(1)

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1. Z. physik. Chem., 2, 840 (1888).

obtained μ_∞ for the sodium salts of the organic acids by calculating the difference between the conductivity of sodium chloride at a certain dilution, e.g. v=32, and at infinite dilution. This difference he assumed to be constant for all sodium salts, and, therefore, by adding it to the conductivity of the sodium salt of any acid at the dilution v=32, μ_∞ for that acid would be obtained. Instead of using this method in this investigation, μ_∞ for the sodium salts was determined directly from conductivity measurements, which are given in the following tables.

Sodium Acetate.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
1024	43.35	62.10	84.82	104.9
2048	44.56	63.83	87.69	107.9
4096	44.60	63.92	87.64	106.8

$$\mu_\infty = 44.56 + 1.520t + 0.00822t^2$$

Sodium Proprionate.

v.	$\mu_v 0^\circ$	$\mu_v 13^\circ.57$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
1024	39.82	59.63	78.60	96.86
2048	40.57	60.99	81.00	100.6
4096	40.58	60.91	81.03	100.8

$$\mu_\infty = 40.57 + 1.378t + 0.00959t^2$$

Sodium Butyrate.

v.	$\mu_v\,0^{\circ}$	$\mu_v\,13^{\circ}.07$	$\mu_v\,25^{\circ}$	$\mu_v\,35^{\circ}$
1024	39.33	58.11	77.69	96.39
2048	40.51	60.29	80.95	100.2
4096	40.54	60.20	80.86	100.1

$$\mu_\infty = 40.51 + 1.401t + 0.00368t^2$$

Sodium Hippurate.

v.	$\mu_v\,0^{\circ}$	$\mu_v\,12^{\circ}$	$\mu_v\,25^{\circ}$	$\mu_v\,35^{\circ}$
1024	35.65	51.30	70.77	86.74
2048	36.23	52.07	71.54	87.98
4096	36.31	52.00	71.60	88.20

$$\mu_\infty = 36.23 + 1.250t + 0.00651t^2$$

Sodium Salts of the Toluic Acids.

v.	$\mu_v\,0^{\circ}$				$\mu_v\,12^{\circ}$			
	o	m	p	α	o	m	p	α
1024	37.82	38.02	38.02	37.89	54.45	54.49	54.41	54.42
2048	38.26	38.25	38.25	38.26	55.05	55.00	55.23	54.87
4096	38.18	38.28	38.28	38.27	54.99	55.09	55.43	54.80

v.	$\mu_v\,25^{\circ}$				$\mu_v\,35^{\circ}$			
	o	m	p	α	o	m	p	α
1024	74.04	74.33	74.90	73.90	91.87	92.16	91.93	91.98
2048	75.28	75.63	75.44	75.46	92.68	92.88	92.40	92.70
4096	74.92	75.59	75.28	75.11	92.58	92.79	92.29	92.29

(α acid)

$$\mu_\infty = 38.26 + 1.320t + 0.00674t^2$$

Sodium Cinnamate.

v.	$\mu_v 0^\circ$	$\mu_v 13^\circ.07$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
1024	27.15	54.59	72.86	89.91
2048	37.69	55.60	74.49	92.06
4096	37.60	55.78	74.41	91.95

$$\mu_\infty = 37.69 + 1.271t + 0.00811t^2$$

Sodium Salicylate.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ.32$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
1024	40.02	57.77	78.09	96.21
2048	40.55	58.58	79.97	98.90
4096	40.56	58.57	80.00	98.90

$$\mu_\infty = 40.51 + 1.353t + 0.00902t^2$$

Sodium Sulphanilate

v.	$\mu_v 0^\circ$	$\mu_v 11^\circ.90$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
1024	38.47	55.37	76.20	93.81
2048	39.52	56.28	77.69	96.05
4096	39.36	56.34	77.70	95.85

$$\mu_\infty = 39.52 + 1.307t + 0.00879t^2$$

Since from the results the above salts show maximum conductivity at v = 2048, the remaining salts were measured only at this dilution.

Sodium Mandelate.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
2048	38.25	55.00	76.00	93.20

$$\mu_\infty = 38.25 + 1.296t + 0.00856t^2$$

Sodium Crotonate

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
2048	39.53	57.25	79.00	97.03

$$\mu_\alpha = 39.53 + 1.416t + 0.00639t^2$$

Sodium Pyromucate

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
2048	40.89	59.30	81.84	100.5

$$\mu_\alpha = 40.89 + 1.478t + 0.00639t^2$$

Sodium Benzoate (Sol. of dry salt)

v.	μ_v 0°	μ_v 14°.54	μ_v 25°	μ_v 35°
2048	38.93	60.25	77.69	96.04

$$\mu_\alpha = 38.93 + 1.348t + 0.00811t^2$$

Sodium Benzoate (By titration).

v.	μ_v 0°	μ_v 14°.54	μ_v 25°	μ_v 35°
2048	38.91	60.33	77.73	96.25

Sodium Gallate

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
2048	37.91	54.50	74.38	91.80

$$\mu_\alpha = 37.91 + 1.259t + 0.00799t^2$$

Sodium o-Aminobenzoate

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
2048	38.20	54.81	75.26	92.51

$$\mu_\alpha = 38.20 + 1.308t + 0.00696t^2$$

Solutions of those sodium salts obtainable from Kahlbaum were made up by weighing out the dry, purified salt, while the remainder were prepared by titrating a solution of the free organic acid with a solution of caustic soda. That this alkali contained no appreciable amount of carbonate was proved by comparing the conductivity of solutions of sodium benzoate made by the two methods. From the above results, it is seen that the titration method is sufficiently accurate.

μ_∞ for the sodium salts of all the toluic acids was determined in order to find out whether there is any difference in the migration velocities of isomeric ions. As there is no difference within the experimental error, the limiting conductivity for isomeric acids can be obtained from measurements on the sodium salt of any one of them. As μ_∞ for the sodium salts of the dibasic acids cannot be experimentally determined, Ostwald's method for calculating this quantity was made use of. If the limiting conductivities of the sodium salts of the monobasic acids are plotted as ordinates against the number of the atoms in the molecule as abscissae, a fairly regular curve is obtained. From this curve μ_∞ for the sodium salts of the dibasic acids may be read off. Even if the value calculated contains an appreciable error, the percentage error introduced into μ_∞ of the organic acid itself will be much less.

The limiting conductivities of ~~many~~ of the organic acids worked with are given below, μ_∞ for the dibasic acids being obtained as in the preceding paragraph.

Limiting Conductivities.

Acid	$\mu_\infty 0^\circ$	μ_∞	$\mu_\infty 25^\circ$	$\mu_\infty 35^\circ$
Acetic	227	292 (12°)	361	412
Propionic	223	260 (6°.9)	354	405
Butyric	223	273 (9°.4)	354	404
Toluic	221	284 (12°)	349	397
Mandelic	221	283 (12°)	349	397
Hippuric	219	280 (12°)	345	392
Malonic	223	250 (4°.9)	355	405
Maleic	223	289 (12°)	353	402
Crotonic	222	286 (12°)	352	402
Racemic	222	286 (12°)	350	398
Pyrotartaric	221	290 (12°)	349	397
Citric	219	311 (18°.1)	345	392
Pyromucic	223	286 (12°)	355	405
Benzoic	222	304 (15°.8)	351	400
Phthalic	221	267 (8°.23)	349	397
Cinnamic	220	248 (5°.3)	348	396
Oxy-benzoic	223	260 (6°.9)	353	403
Gallic	220	254 (6°.5)	348	396
Sulphanilic	222	255 (6°.3)	351	400
Aminobenzoic	221	260 (7°.5)	349	396

Results.--The results are tabulated in the following pages, molecular conductivities (μ_v) being expressed in Siemen's units. The temperature coefficients expressed in conductivity units and percentages need no explanation.

Table I.--Acetic Acid. Molecular Conductivity

v.	$\mu_v 0^\circ$	$\mu_v 9^\circ.2$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
2	1.270	1.560	2.089	2.359
8	2.656	3.292	4.342	4.948
32	5.328	6.612	8.699	9.912
128	10.48	13.04	17.11	19.46
512	20.45	25.40	33.24	37.75
1024	28.03	34.95	45.87	52.09
2048	39.05	48.65	63.00	70.89

Temperature Coefficients.

v.	0°-$9^\circ.2$		$9^\circ.2$--25°		25°--35°	
	Cond. units	Per cent	Cond.units	Per cent	Cond.units	Per cent
2	0.03	2.49	0.03	2.15	0.03	1.30
8	0.07	2.61	0.07	2.02	0.06	1.40
32	0.14	2.62	0.13	2.00	0.12	1.39
128	0.28	2.66	0.26	1.98	0.24	1.37
512	0.54	2.63	0.50	1.96	0.45	1.36
1024	0.72	2.57	0.69	1.95	0.62	1.32
2048	1.04	2.67	0.91	1.87	0.79	1.25

Percentage Dissociation.

v.	$\alpha 0^\circ$	$\alpha 9^\circ.2$	$\alpha 25^\circ$	$\alpha 35^\circ$
2	0.56	0.56	0.58	0.57
8	1.18	1.19	1.20	1.20
32	2.37	2.40	2.41	2.41
128	4.62	4.71	4.74	4.72
512	8.80	9.13	9.21	9.16
1024	12.35	12.51	12.71	12.64
2048	17.20	17.56	17.45	17.21

Dissociation Constants x 10^4

v.	0°	$9^\circ.2$	25°	35°
2	0.157	0.159	0.169	0.165
8	0.175	0.179	0.183	0.182
32	0.179	0.184	0.186	0.185
128	0.175	0.182	0.184	0.183
512	0.166	0.179	0.182	0.181
1024	0.170	0.175	0.181	0.179
2048	0.174	0.179	0.180	0.175

Table II.--Propionic Acid.

Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 6^\circ.9$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
2	1.030	1.217	1.700	1.913
8	2.291	2.700	3.704	4.207
32	4.631	5.450	7.436	8.422
128	9.004	10.60	14.57	16.50
512	17.47	20.59	28.40	32.14
1024	23.82	28.03	38.94	44.06
2048	32.43	39.24	53.47	60.28

Temperature Coefficients

v.	0°--$6^\circ.9$		$6^\circ.9$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
2	0.03	2.63	0.03	2.19	0.02	1.25
8	0.06	2.59	0.06	2.05	0.05	1.36
32	0.12	2.56	0.11	2.01	0.10	1.33
128	0.23	2.58	0.22	2.07	0.19	1.32
512	0.45	2.59	0.43	2.10	0.37	1.32
1024	0.61	2.56	0.59	2.11	0.51	1.31
2048	0.84	2.52	0.79	2.01	0.68	1.27

Percentage Dissociation

v.	$\alpha 0^\circ$	$\alpha 6^\circ.9$	$\alpha 25^\circ$	$\alpha 35^\circ$
2	0.46	0.47	0.48	0.47
8	1.03	1.04	1.05	1.04
32	2.08	2.10	2.10	2.08
128	4.04	4.08	4.12	4.07
512	7.83	7.92	8.02	7.93
1024	10.69	10.78	11.00	10.87
2048	14.99	15.09	15.10	14.88

Dissociation Constants x 10^4

v.	0°	$6^\circ.9$	25°	35°
2	0.107	0.111	0.116	0.112
8	0.133	0.136	0.138	0.137
32	0.138	0.140	0.141	0.138
128	0.133	0.135	0.138	0.135
512	0.130	0.133	0.137	0.134
1024	0.125	0.127	0.123	0.130
2048	0.129	0.131	0.131	0.27

Table III.--N-Butyric Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 9.^\circ 4$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
2	1.090	1.341	1.730	1.930
8	2.501	3.062	3.891	4.351
32	5.072	6.230	7.902	8.801
128	10.00	12.23	15.45	17.14
512	19.44	23.79	29.86	33.00
1024	26.82	32.83	41.22	45.26
2048	37.37	45.63	89.20	62.71

Temperature Coefficients.

V.	0°--9.°4		9.°4--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
2	0.03	2.44	0.03	1.87	0.02	1.16
8	0.06	2.38	0.05	1.74	0.05	1.19
32	0.12	2.43	0.11	1.72	0.09	1.14
128	0.24	2.44	0.21	1.69	0.17	1.09
512	0.46	2.38	0.39	1.64	0.31	1.05
1024	0.64	2.38	0.54	1.64	0.40	0.98
2048	0.88	2.35	0.74	1.61	0.55	0.96

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha 9.^\circ 4$	$\alpha 25^\circ$	$\alpha 35^\circ$
2	0.49	0.49	0.49	0.48
8	1.12	1.12	1.10	1.08
32	2.27	2.28	2.23	2.18
128	4.48	4.48	4.36	4.24
512	8.72	8.71	8.44	8.17
1024	12.02	12.02	11.64	11.20
2048	16.76	16.71	16.15	15.52

Dissociation Constants x 10^4

v.	0°	9.°4	25°	35°
2	0.120	0.120	0.120	0.115
8	0.159	0.159	0.153	0.147
32	0.165	0.166	0.157	0.152
128	0.164	0.164	0.152	0.147
512	0.163	0.163	0.152	0.142
1024	0.161	0.161	0.150	0.138
2048	0.165	0.164	0.152	0.139

Table IV.--iso-Butyric Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 16^\circ.46$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
2	1.034	1.450	1.633	1.841
8	2.453	3.412	3.821	4.272
32	4.912	6.809	7.621	8.514
128	9.736	13.48	15.13	16.90
512	18.91	26.01	29.30	32.70
1024	26.32	36.18	40.90	45.54
2048	35.96	49.22	55.01	61.35

Temperature Coefficients.

v.	0°--16°.46		16°.46--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
2	0.03	2.45	0.02	1.48	0.02	1.27
8	0.06	2.38	0.05	1.40	0.05	1.18
32	0.12	2.35	0.10	1.40	0.09	1.17
128	0.23	2.33	0.19	1.43	0.18	1.17
1512	0.43	2.28	0.36	1.41	0.34	1.16
1024	0.60	2.28	0.51	1.41	0.46	1.13
2048	0.81	2.24	0.68	1.38	0.63	1.15

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 16^\circ.46$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
2	0.47	0.47	0.46	0.46
8	1.10	1.10	1.08	1.06
32	2.20	2.20	2.15	2.11
128	4.37	4.35	4.27	4.18
512	8.48	8.39	8.28	8.09
1024	11.80	11.67	11.55	11.27
2048	16.13	15.88	15.54	15.19

Dissociation Constants x 10^4

v.	0°	16°.46	25°	35°
2	0.108	0.110	0.108	0.108
8	0.153	0.153	0.147	0.141
32	0.155	0.154	0.148	0.142
128	0.156	0.154	0.149	0.143
512	0.154	0.150	0.146	0.139
1024	0.154	0.150	0.147	0.140
2048	0.151	0.146	0.140	0.133

Table V.--Phenylacetic Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 13°25	μ_v 25°	μ_v 35°
32	9.001	11.76	14.15	15.90
128	17.82	23.39	27.96	31.26
512	33.35	43.51	52.39	58.55
1024	45.68	59.59	71.63	79.84
2048	61.00	79.49	95.50	106.3

Temperature Coefficients

V.	0°--13°25		13°25--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.21	2.32	0.20	1.73	0.18	1.23
128	0.41	2.32	0.40	1.70	0.33	1.18
512	0.77	2.30	0.76	1.72	0.62	1.18
1024	1.05	2.30	1.03	1.72	0.82	1.15
2048	1.40	2.29	1.36	1.71	1.08	1.13

Percentage Dissociation.

v.	α 0°	α 13°25	α 25°	α 35°
32	4.07	4.06	4.05	4.01
128	8.06	8.06	8.01	7.87
512	15.09	15.01	14.97	14.75
1024	20.67	20.55	20.52	20.11
2048	27.60	27.41	27.36	26.77

Dissociation Constants x 10^4

v.	0°	13°25	25°	35°
32	0.540	0.536	0.536	0.522
128	0.552	0.553	0.545	0.526
512	0.524	0.518	0.515	0.499
1024	0.526	0.519	0.518	0.494
2048	0.514	0.507	0.504	0.478

Table VI.--Mandelic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
8	12.60	16.10	19.86	22.45
32	24.49	31.21	38.56	43.62
128	46.40	59.64	72.96	82.39
512	82.21	106.1	129.6	146.2
1024	106.0	135.2	167.4	188.7
2048	132.4	168.3	205.5	234.5

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.29	2.32	0.29	1.80	0.26	1.30
32	0.56	2.29	0.56	1.81	0.51	1.31
128	1.10	2.38	1.02	1.72	0.94	1.29
512	1.99	2.42	1.81	1.71	1.66	1.28
1025	2.43	2.30	2.48	1.83	2.13	1.27
2048	2.99	2.26	2.86	1.70	2.90	1.40

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 12^\circ$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
8	5.70	5.69	5.69	5.65
32	11.09	11.03	11.05	10.98
128	20.99	20.78	20.90	20.75
512	37.20	36.98	37.15	36.84
1024	47.96	47.76	47.97	47.53
2048	59.91	59.47	59.03	59.06

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
8	4.32	4.29	4.29	4.24
32	4.30	4.27	4.29	4.24
128	4.36	4.26	4.31	4.25
512	4.30	4.24	4.30	4.20
1024	4.32	4.26	4.32	4.21
2048	4.37	4.26	4.16	4.16

Table VII.--Hippuric Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
128	33.96	44.42	55.17	62.15
512	61.66	80.54	100.2	113.5
1024	81.10	105.8	131.1	147.2
2048	103.0	134.1	165.8	185.9

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
128	0.87	2.57	0.83	1.86	0.70	1.27
512	1.57	2.55	1.52	1.84	1.25	1.25
1024	206	2.54	1.95	1.84	1.61	1.23
2048	2.59	2.52	2.44	1.82	2.01	1.21

Percentage Dissociation.

v.	$\alpha 0^\circ$	$\alpha 12^\circ$	$\alpha 25^\circ$	$\alpha 35^\circ$
128	15.51	15.86	15.99	15.85
512	28.16	28.76	29.04	28.96
1024	37.03	37.79	38.00	37.55
2048	47.03	47.88	48.06	47.42

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
128	2.22	2.34	2.38	2.33
512	2.16	2.27	2.32	2.31
1024	2.13	2.24	2.28	2.26
2048	2.04	2.15	2.17	2.09

Table VIII.--Malonic Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 4°9	μ_v 25°	μ_v 35°
2	11.81	13.34	19.61	22.51
8	23.19	26.20	38.40	44.03
32	43.51	49.25	72.23	82.55
128	78.30	88.83	129.8	148.2
512	127.1	143.4	208.7	237.4
1024	153.3	173.2	251.2	284.8
2048	176.9	199.1	289.1	327.6

Temperature Coefficients.

v.	0° --4°9		4°9 --25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent.
2	0.31	2.64	0.31	2.34	0.29	1.48
8	0.61	2.66	0.61	2.32	0.58	1.47
32	1.17	2.69	1.14	2.32	1.03	1.43
128	2.09	2.67	2.04	2.30	1.84	1.42
512	3.33	2.62	3.25	2.27	2.87	1.38
1024	4.06	2.65	3.88	2.24	3.36	1.34
2048	4.53	2.56	4.48	2.25	3.75	1.30

Percentage Dissociation.

v.	α 0°	α 4°9	α 25°	α 35°
2	5.30	5.34	5.53	5.55
8	10.40	10.48	10.81	10.87
32	19.57	19.70	20.34	20.38
128	35.12	35.53	36.58	36.59
512	56.99	57.36	58.80	58.60
1024	68.74	69.28	70.76	70.31
2048	79.32	79.66	81.45	80.89

Dissociation Constants x 10^4

v.	0°	4°9	25°	35°
2	14.8	15.0	16.1	16.4
8	15.1	15.3	16.4	16.5
32	14.8	15.1	16.3	16.3
128	14.8	15.3	16.4	16.5
512	14.8	15.1	16.4	16.2
1024	14.8	15.3	16.7	16.3
2048	14.9	15.3	17.5	16.8

Table IX.--Succinic Acid. Molecular Conductivity.

v.	$\mu_v\ 0^\circ$	$\mu_v\ 5^\circ.7$	$\mu_v\ 25^\circ$	$\mu_v\ 35^\circ$
8	4.570	5.371	8.032	9.251
32	9.211	10.72	16.01	18.36
128	18.24	21.35	31.24	35.80
512	34.75	40.59	59.34	67.87
1024	47.89	55.91	81.31	92.89
2048	64.61	75.29	109.6	124.8

Temperature Coefficients.

	0°--$5^\circ.7$		$5^\circ.7$--25°		25°--35°	
v.	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.14	3.07	0.14	2.57	0.12	1.52
32	0.28	3.03	0.27	2.56	0.24	1.47
128	0.55	2.99	0.51	2.40	0.46	1.46
512	1.02	2.95	0.97	2.39	0.85	1.44
1024	1.41	2.94	1.32	2.36	1.16	1.42
2048	1.87	2.90	1.78	2.36	1.52	1.39

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 5^\circ.7$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
8	2.05	2.15	2.26	2.28
32	4.13	4.29	4.51	4.53
128	8.18	8.54	8.80	8.84
512	15.58	16.24	16.72	16.76
1024	20.47	22.37	22.91	22.91
2048	28.97	30.11	30.88	30.81

Dissociation Constants x 10^4

v.	0°	$5^\circ.7$	25°	35°
8	0.537	0.590	0.655	0.667
32	0.556	0.600	0.666	0.673
128	0.569	0.623	0.664	0.670
512	0.562	0.615	0.655	0.659
1024	0.572	0.629	0.665	0.665
2048	0.577	0.634	0.675	0.670

Table X.--Maleic Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
32	108.1	141.0	175.4	198.8
128	159.2	206.6	256.2	290.7
512	198.5	257.4	317.6	360.8
1024	212.8	274.7	337.9	384.6
2048	221.1	286.6	352.3	400.8

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	2.74	2.54	2.65	1.88	2.34	1.34
128	3.95	2.48	3.82	1.85	3.45	1.35
512	4.85	2.50	4.63	1.80	4.32	1.36
1024	5.14	2.43	4.86	1.77	4.67	1.38
2048	5.46	2.47	5.05	1.76	4.85	1.41

Percentage Dissociation.

v.	α 0°	α 12o	α 25°	α 35°
32	48.48	48.78	49.72	49.46
128	71.50	71.50	72.56	72.31
512	89.00	89.06	89.97	89.76
1024	95.06	95.06.	95.72	95.68
2048	99.10	99.17	99.79	99.72

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
32	143.	145.	154.	151.
128	141.	140.	150.	148.
512	141.	142.	158.	154.
1024	179.	179.	209.	208.
2048	---	----	---	---

Table XI.--Fumaric Acid. Molecular Conductivity.

v.	$\mu_v\,0^{\circ}$	$\mu_v\,12^{\circ}$	$\mu_v\,25^{\circ}$	$\mu\,35^{\circ}$
32	35.46	46.66	58.00	65.79
128	65.67	86.42	107.2	121.2
512	114.1	149.1	184.9	209.6
1024	141.4	184.9	228.1	258.1
2048	176.5	229.0	281.0	318.1

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. Units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.94	2.64	0.87	1.87	1.78	1.19
128	1.73	2.63	1.60	1.85	1.46	1.20
512	2.92	2.56	2.75	1.85	2.47	1.18
1024	3.62	2.56	3.32	1.80	3.00	1.17
2048	4.33	2.45	4.00	1.75	3.71	1.17

Percentage Dissociation.

v.	$\alpha\,0^{\circ}$	$\alpha\,12^{\circ}$	$\alpha\,25^{\circ}$	$\alpha\,35^{\circ}$
32	15.90	16.14	16.43	16.37
128	29.45	29.90	30.37	30.15
512	51.17	51.59	52.37	52.14
1024	63.43	63.97	64.62	64.21
2048	59.14	79.23	79.60	79.12

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
32	9.40	9.72	10.1	10.0
128	9.61	9.97	10.4	10.2
512	10.5	10.7	11.3	11.0
1024	10.7	11.1	11.5	11.2
2048	14.7	14.8	15.2	14.6

Table XII.--Citraconic Acid. Molecular Conductivity.

v.	μ_v 0°	12°	25°	35°
32	68.66	85.82	103.0	115.1
128	114.3	144.0	173.4	194.4
512	165.9	210.2	255.4	288.2
1024	186.1	237.0	289.1	226.5
2048	200.5	257.1	315.0	356.0

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	1.43	2.08	1.32	1.54	1.21	1.18
128	2.48	2.17	2.26	1.57	2.10	1.21
512	3.69	2.23	3.48	1.65	3.28	1.28
1024	4.24	2.28	4.00	1.69	3.74	1.29
2048	4.70	2.34	4.46	1.74	4.10	1.30

Percentage Dissociation.

v.	α 0°	α 12°	α 25°	α 35°
32	31.02	30.16	29.34	28.77
128	51.64	50.60	49.40	48.60
512	74.98	73.86	72.76	72.04
1024	84.09	83.28	82.37	81.62
2048	90.59	90.31	89.74	89.01

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
32	43.6	40.7	38.1	36.3
128	43.1	40.5	37.7	35.9
512	43.9	40.8	38.0	36.2
1024	43.4	40.5	37.6	35.4
2048	42.6	41.0	38.3	35.3

Table XIII.--Mesaconic Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
32	33.31	42.85	52.00	58.04
128	62.60	80.18	97.30	108.5
512	108.0	139.0	168.5	188.2
1024	134.7	172.9	209.8	234.0
2048	160.9	206.3	250.0	278.8

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.80	2.39	0.70	1.63	0.60	1.16
128	1.47	2.36	1.32	1.64	1.12	1.15
512	2.54	2.35	2.27	1.63	1.97	1.16
1024	3.78	2.37	2.84	1.64	2.42	1.15
2048	4.09	2.35	3.36	1.63	2.88	1.15

Percentage Dissociation.

v.	α 0°	α 12°	α 25°	α 35°
32	15.05	15.04	14.81	14.51
128	28.29	28.17	27.72	27.13
512	48.79	48.67	48.00	47.06
1024	60.87	60.74	59.77	58.49
2048	72.69	72.49	71.22	69.69

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
32	8.4	8.4	8.1	7.7
128	8.7	8.6	8.3	7.9
512	9.1	9.0	8.6	8.2
1024	9.3	9.2	8.7	8.1
2048	9.5	9.3	8.6	9.8

Table XIV.--Itaconic Acid. Molecular Conductivity.

v.	μ_v 0°	v 18°12	25°	v 35°
32	13.50	20.77	23.68	27.22
128	26.00	39.95	45.52	52.21
512	49.51	74.57	84.74	97.11
1024	66.70	99.51	113.3	129.8
2048	87.91	129.9	147.3	167.5

Temperature Coefficients.

v.	0°--18°12		18°12--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.40	2.97	0.42	2.04	0.35	1.50
128	0.77	2.97	0.83	2.03	0.67	1.47
512	1.38	2.79	1.48	1.98	1.24	1.46
1024	1.81	2.71	2.01	2.01	1.65	1.45
2048	2.32	2.64	2.53	1.95	2.02	1.44

Percentage Dissociation.

v.	α 0°	α 18°12	α 25°	α 35°
32	6.10	6.57	6.75	6.80
128	11.75	12.64	12.97	13.05
512	22.38	23.60	24.15	24.28
1024	30.14	31.49	32.28	32.45
2048	39.72	41.11	41.98	41.87

Dissociation Constants x 10^4

v.	0°	18°12	25°	35°
32	1.24	1.45	1.53	1.55
128	1.23	1.43	1.51	1.53
512	1.26	1.43	1.50	1.52
1024	1.27	1.42	1.50	1.52
2048	1.28	1.40	1.49	1.47

Table XV.--Crotonic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
8	2.752	3.640	4.550	5.177
32	5.526	7.312	9.123	10.31
128	10.92	14.49	18.00	20.29
512	21.25	28.23	35.15	39.85
1024	29.14	38.50	48.04	54.60
2048	39.78	53.41	65.33	74.19

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.07	2.69	0.07	1.92	0.06	1.38
32	0.15	2.69	0.14	1.91	0.12	1.31
128	0.30	2.72	0.27	1.86	0.23	1.27
512	0.58	2.74	0.53	1.89	0.47	1.34
1024	0.78	2.68	0.73	1.91	0.66	1.37
2048	1.05	2.67	0.99	1.90	0.89	1.36

Percentage Dissociation.

v.	$\alpha\,0^\circ$	$\alpha\,12^\circ$	$\alpha\,25^\circ$	$\alpha\,35^\circ$
8	1.24	1.27	1.29	1.29
32	2.49	2.56	2.59	2.57
128	4.92	5.07	5.11	5.05
512	9.57	9.87	10.00	9.91
1024	13.12	13.46	13.65	13.58
2048	17.74	18.32	18.57	18.45

Dissociation Constants x 10°

v.	0°	12°	25°	35°
8	0.195	0.205	0.212	0.211
32	0.199	0.210	0.215	0.211
128	0.199	0.211	0.215	0.210
512	0.198	0.211	0.216	0.213
1024	0.194	0.205	0.211	0.208
2048	0.187	0.201	0.207	0.204

Table XVI.--Racemic Acid. Molecular Conductivity.

v.	μ, 0°	μ 12°	25°	35°
8	18.02	24.35	30.97	35.98
32	34.60	46.85	59.65	69.03
128	63.24	85.15	108.2	124.7
512	110.6	147.8	187.0	215.1
1024	139.0	183.7	230.0	264.3
2048	175.3	231.5	290.4	333.8

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	1.53	2.93	0.51	2.09	0.50	1.62
32	1.02	2.95	0.99	2.10	0.95	1.59
128	1.83	2.89	1.77	2.08	1.65	1.53
512	3.10	2.80	3.02	2.04	2.81	1.50
1024	3.73	2.68	3.56	2.94	3.43	1.49
2048	4.68	2.67	4.53	1.95	4.34	1.50

Percentage Dissociation.

v.	α 0°	α 12°	α 25°	α 35°
8	8.15	8.51	8.85	9.04
32	15.66	16.38	17.04	17.34
128	28.62	29.77	30.91	31.32
512	50.03	51.68	53.42	54.04
1024	62.90	64.22	65.70	66.40
2048	79.30	80.93	82.96	83.85

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
8	9.1	9.9	10.8	11.2
32	9.1	10.0	10.9	11.3
128	9.0	9.9	10.8	11.2
512	9.8	10.8	12.0	12.4
1024	10.4	11.3	12.3	12.8
2048	14.8	16.8	19.7	21.3

Table XVII.--Pyrotartaric Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
8	5.403	7.150	9.045	10.41
32	10.94	14.41	18.13	20.80
128	21.08	27.68	35.00	40.00
512	40.45	53.06	67.02	76.56
1024	54.18	71.31	89.73	102.4
2048	73.00	96.00	120.3	137.7

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.15	2.70	0.15	2.04	0.14	1.49
32	0.29	2.64	0.29	1.99	0.27	1.47
128	0.56	2.61	0.56	2.03	0.50	1.43
512	1.05	2.60	1.07	2.02	0.95	1.42
1024	1.43	2.63	1.42	1.99	1.27	1.42
2048	1.92	2.62	1.87	1.95	1.74	1.45

Percentage Dissociation.

v.	α 6°	α 12°	α 25°	α 35°
8	2.44	2.46	2.59	2.62
32	4.95	4.97	5.20	5.24
128	9.54	9.55	10.03	10.08
512	18.30	18.30	19.21	19.29
1024	24.51	24.60	25.71	25.79
2048	33.03	33.11	34.46	34.69

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
8	77	78	86	89
32	81	81	89	90
128	79	79	87	88
512	80	80	89	90
1024	78	78	87	88
2048	80	80	88	90

Table XVIII.--Citric Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 18^\circ.10$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
8	15.64	24.34	27.50	32.05
32	30.27	46.71	52.76	61.42
128	55.94	86.40	97.30	112.7
512	97.22	148.3	167.6	195.1
1024	127.3	193.3	218.1	251.9
2048	153.2	229.3	257.9	297.8

Temperature Coefficients.

v.	0°--$18^\circ.10$		$18^\circ.10$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.48	3.07	0.46	1.88	0.46	1.66
32	0.91	3.00	0.87	1.87	0.87	1.64
128	1.68	3.01	1.58	1.83	1.54	1.58
512	2.82	2.90	2.80	1.87	2.66	1.58
1024	3.64	2.86	3.59	1.86	3.38	1.55
2048	4.20	2.75	4.15	1.81	3.99	1.55

Percentage Dissociation

v.	$\alpha\ 0^\circ$	$\alpha\ 18^\circ.10$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
8	7.14	7.82	7.97	8.18
32	13.82	15.03	15.30	15.67
128	25.55	27.77	28.20	28.74
512	44.40	47.46	48.59	49.76
1024	58.13	62.16	63.23	64.25
2048	69.97	73.72	74.74	75.98

Dissociation Constants x 10^4

v.	0°	$18^\circ.10$	25°	35°
8	6.87	8.30	8.63	9.10
32	6.92	8.30	8.63	9.10
128	6.85	8.34	8.66	9.05
512	6.92	8.38	8.97	9.63
1024	7.88	9.96	10.6	11.3
2048	7.96	10.1	10.8	11.7

Table XIX.--Pyromucic Acid. Molecular Conductivity.

v.	μ_v 0°	μ_v 12°	μ_v 25°	μ_v 35°
8	17.47	22.01	26.29	28.94
32	34.24	42.76	51.15	56.37
128	62.90	79.22	94.61	104.5
512	107.1	136.4	163.2	108.0
1024	132.0	169.0	201.3	222.9
2048	159.5	203.0	245.1	270.1

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
8	0.38	2.18	0.33	1.50	0.28	1.05
32	0.71	2.08	0.65	1.51	0.52	1.04
128	1.36	2.16	1.18	1.50	0.99	1.05
512	2.44	2.28	2.06	1.51	1.68	1.03
1024	3.08	2.31	2.49	1.47	2.06	1.02
2048	3.62	2.27	3.24	1.59	2.50	1.02

Percentage Dissociation.

v.	α 0°	α 12°	α 25°	α 35°
8	7.83	7.64	7.38	7.15
32	15.36	14.85	14.41	13.92
128	28.21	27.51	26.65	25.80
512	48.03	47.36	45.97	44.44
1024	59.20	58.68	56.99	55.03
2048	71.53	70.49	69.05	66.70

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
8	8.3	7.9	7.4	6.9
32	8.7	8.1	7.6	7.0
128	8.7	8.1	7.6	7.0
512	8.7	8.3	7.6	6.9
1024	8.4	8.1	7.4	6.6
2048	8.7	8.2	7.5	6.5

Table XX.--Benzoic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$.	$\mu_v 15^\circ.80$	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.
64	13.42	19.08	22.29	25.40
128	18.79	26.93	31.39	35.71
512	36.00	51.30	59.79	67.81
1024	47.63	68.33	79.56	90.11
2048	64.95	91.30	106.0	119.7

Temperature Coefficients.

v.	0°--$15^\circ.80$		$15^\circ.80$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	0.36	2.67	0.35	1.83	0.31	1.40
128	0.50	2.66	0.49	1.81	0.43	1.38
512	0.97	2.69	0.92	1.81	0.80	1.35
1024	1.26	2.64	1.22	1.79	1.06	1.33
2048	1.67	2.57	1.60	1.75	1.37	1.30

Percentage Dissociation

v.	$\alpha\ 0^\circ$	$\alpha\ 15^\circ.80$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
64	6.04	6.32	6.35	6.34
128	8.46	8.92	8.94	8.92
512	16.21	17.00	17.02	16.94
1024	21.45	22.62	22.67	22.52
2048	29.25	30.24	30.20	29.92

Dissociation Constants x 10^4

v.	0°	$15^\circ.80$	25°	35°
64	0.607	0.666	0.672	0.672
128	0.611	0.682	0.686	0.684
512	0.613	0.679	0.683	0.676
1024	0.572	0.646	0.649	0.640
2048	0.591	0.640	0.638	0.624

Table XXI.--o-Toluic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
512	54.71	68.32	81.09	88.44
1024	71.65	89.87	106.7	116.7
2048	95.06	118.7	141.0	154.7

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
512	1.13	2.07	0.98	1.44	0.74	0.91
1024	1.52	2.11	1.29	1.44	1.00	0.94
2048	1.93	2.03	1.72	1.44	1.33	0.94

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 12^\circ$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
512	24.76	24.11	23.23	22.20
1024	32.44	31.71	30.50	29.47
2048	43.01	41.75	40.54	39.16

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
512	1.59	1.49	1.37	1.25
1024	1.52	1.44	1.32	1.30
2048	1.59	1.46	1.35	1.22

Table XXII.--m-Toluic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
512	33.05	43.57	54.60	62.05
1024	45.20	59.43	74.16	83.93
2048	61.24	80.79	100.4	113.1

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
512	0.88	2.65	0.85	1.95	0.75	1.37
1024	1.19	2.62	1.13	1.91	0.98	1.32
2048	1.63	2.66	1.51	1.87	1.27	1.27

Percentage Dissociation.

v.	$\alpha 0^\circ$	$\alpha 12^\circ$	$\alpha 25^\circ$	$\alpha 35^\circ$
512	14.95	15.44	15.64	15.63
1024	20.45	21.05	21.25	21.14
2048	27.71	28.63	28.77	28.49

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
512	0.513	0.550	0.567	0.565
1024	0.513	0.548	0.560	0.554
2048	0.519	0.560	0.567	0.554

Table XXIII.--p-Toluic Acid. Molecular Conductivity.

v.	μ 0°	12°	25°	35°
512	-----	-----	48.48	55.44
1024	39.63	52.52	66.13	75.54
2048	54.12	71.75	89.96	103.5

Temperature Coefficients

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
512	-----	----	----	----	0.70	1.44
1024	1.07	2.76	1.05	1.99	0.94	1.42
2048	1.47	2.72	1.40	1.95	0.35	1.50

Percentage Dissociation

v.	α 0°	α 12°	α 25°	α 35°
512	-----	-----	13.89	13.96
1024	17.93	18.49	18.95	19.02
2048	24.49	25.26	25.78	26.07

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
512	-----	-----	0.438	0.433
1024	0.383	0.410	0.433	0.437
2048	0.388	0.417	0.437	0.449

Table XXIV.--O-Phthalic Acid. Molecular Conductivity.

v.	μ 0°	8°.23	25°	35°
64	55.98	66.45	85.92	96.48
128	74.56	88.32	114.8	128.9
512	122.3	145.7	189.2	212.5
1024	148.2	177.1	231.9	259.7
2048	174.2	208.4	272.7	306.0

Temperature Coefficients.

v.	0°--8°.23		8°.23--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	1.27	2.27	1.16	1.75	1.06	1.23
128	1.67	2.24	1.58	1.79	1.41	1.23
512	2.84	2.33	2.59	1.78	2.33	1.23
1024	3.51	2.37	3.27	1.85	2.78	1.20
2048	4.16	2.39	3.83	1.84	3.33	1.22

Percentage Dissociation.

v.	α 0°	α 8°.23	α 25o	α 35°
64	25.33	24.89	24.62	24.31
128	33.75	33.09	32.90	32.47
512	55.34	54.58	54.23	53.52
1024	67.07	66.33	66.45	65.42
2048	78.81	78.05	78.14	77.07

Dissociation Constants x 10^4

v.	0°	8°.23	25°	35°
64	13.4	12.9	12.6	12.2
128	13.4	12.8	12.6	12.2
512	13.4	12.8	12.5	12.0
1024	13.3	12.8	12.8	12.1
2048	14.3	13.6	13.6	12.7

Table XXV.--Cinnamic Acid. Molecular Conductivity.

v.	μ, 0°	μ, 5°.3	μ, 25°	μ 35°
512	26.50	30.67	44.60	50.70
1024	36.40	42.11	61.22	69.63
2048	49.69	57.40	83.45	94.81

Temperature Coefficients.

v.	0°--5°.3		5°.3--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
512	0.79	2.97	0.71	2.31	0.61	1.37
1024	1.08	2.96	0.97	2.30	0.84	1.37
2048	1.46	2.93	1.32	2.30	1.14	1.36

Percentage Dissociation.

v.	α 0°	α 5°.3	α 25°	α 35°
512	12.04	12.37	12.81	12.80
1024	16.55	16.97	17.59	17.58
2048	22.08	23.14	23.98	23.94

Dissociation Constants x 10^4

v.	0°	5°.3	25°	35°
512	0.322	0.341	0.368	0.367
1024	0.320	0.339	0.367	0.366
2048	0.305	0.342	0.370	0.368

Table XXVI.--Salicylic Acid. Molecular Conductivity.

v.	$\mu_v 0^{\circ}$	$\mu_v 6^{\circ}.9$	$\mu_v 25^{\circ}$	$\mu_v 35^{\circ}$
64	-----	-----	80.50	92.80
128	62.65	75.59	108.3	125.1
512	105.4	126.4	181.2	207.0
1024	130.7	156.9	223.2	255.4
2048	153.8	183.9	259.9	295.7

Temperature Coefficients

v.	0°--$6^{\circ}.9$		$6^{\circ}.9$--25°		25°--35°	
	Cond. uhits	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	----	----	----	----	1.23	1.53
128	1.88	2.99	1.83	2.42	1.68	1.55
512	3.12	2.96	3.00	2.37	2.58	1.42
1024	3.80	2.91	3.63	2.31	3.22	1.41
2048	4.36	2.84	2.16	2.26	3.58	1.38

Percentage Dissociation

v.	$\alpha\ 0^{\circ}$	$\alpha\ 6^{\circ}.9$	$\alpha\ 25^{\circ}$	$\alpha\ 35^{\circ}$
64	-----	-----	22.80	23.02
128	28.09	29.06	30.68	31.03
512	47.28	48.62	51.34	51.37
1024	58.60	60.34	63.22	63.37
2048	68.96	70.73	73.62	73.36

Dissociation Constants x 10^4

v.	0°	$6^{\circ}.9$	25°	35°
64	-----	----	10.5	10.7
128	8.6	9.3	10.6	10.9
512	8.3	9.0	10.6	10.6
1024	8.1	9.0	10.6	10.7
2048	7.5	8.4	9.4	9.9

Table XXVII.--m-Oxybenzoic Acid. Molecular Conductivity.

v.	$\mu_v\ 0^\circ$	$\mu_v\ 13^\circ.22$	$\mu_v\ 25^\circ$	$\mu_v\ 35^\circ$
64	14.65	19.97	24.35	27.74
128	20.48	27.85	33.95	38.63
512	39.04	52.89	64.50	73.28
1024	53.09	72.01	87.80	99.70
2048	71.20	96.03	116.9	132.6

Temperature Coefficients.

v.	0°--$13^\circ.22$		13.22°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	0.40	2.75	0.37	1.86	0.34	0.39
128	0.56	2.72	0.52	1.86	0.47	1.38
512	1.05	2.68	0.99	1.86	0.88	1.36
1024	1.44	2.71	1.31	1.81	1.19	1.36
2048	1.94	2.74	1.72	1.78	1.57	1.34

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 13^\circ.22$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
64	6.57	6.82	6.90	6.88
128	9.18	9.50	9.62	9.58
512	17.51	18.05	18.27	18.19
1024	23.81	24.56	24.87	24.74
2048	31.93	32.77	33.12	32.91

Dissociation Constants x 10^4

v.	0°	$13^\circ.22$	25°	35°
64	0.722	0.779	0.799	0.795
128	0.725	0.780	0.799	0.794
512	0.725	0.776	0.798	0.789
1024	0.726	0.781	0.804	0.794
2048	0.715	0.780	0.801	0.788

Table XXVIII.--p-Oxybenzoic Acid. Molecular Conductivity.

v.	$\mu_v\ 0^\circ$	$\mu_v\ 13^\circ.23$	$\mu_v\ 25^\circ$	$\mu_v\ 35^\circ$
64	8.746	11.99	14.79	16.97
128	12.29	16.81	20.69	23.71
512	23.87	32.45	39.96	45.77
1024	33.03	44.91	55.30	63.24
2048	44.40	60.39	74.14	85.60

Temperature Coefficients.

v.	0°--$13^\circ.23$		$13^\circ.23$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cont
64	0.25	2.80	0.24	1.98	0.22	1.46
128	0.34	2.78	0.33	1.96	0.30	1.46
512	0.65	2.72	0.64	1.97	0.58	1.45
1024	0.90	2.72	0.88	1.97	0.79	1.44
2048	1.21	2.72	0.17	1.94	1.05	1.41

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 13^\circ.23$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
64	3.92	4.09	4.19	4.21
128	5.51	5.74	5.86	5.88
512	10.70	11.08	11.32	11.36
1024	14.81	15.32	15.66	15.70
2048	19.91	20.61	21.00	21.00

Dissociation Constants x 10^4

v.	0°	$13^\circ.23$	25°	35°
64	0.250	0.273	0.286	0.289
128	0.251	0.273	0.285	0.287
512	0.251	0.269	0.282	0.284
1024	0.252	0.271	0.284	0.285
2048	0.242	0.261	0.273	0.273

Table XXIX.--Gallic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 6^\circ.5$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
64	9.790	11.66	16.90	19.36
128	14.01	16.55	23.60	27.10
512	28.89	34.08	48.33	55.12
1024	37.84	44.63	62.50	71.18
2048	51.50	60.72	85.02	96.7

Temperature Coefficients.

v.	0°--$6^\circ.5$		$6^\circ.5$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	0,29	2.94	0.28	2.43	0.25	1.46
128	0.39	2.79	0.38	2.30	0.35	1.48
512	0.80	2.77	0.77	2.26	0.68	1.41
1024	1.05	2.76	0.97	2.17	0.87	1.39
2048	1.42	2.75	1.31	2.16	1.17	1.33

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 6^\circ.5$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
64	4.44	4.59	4.86	4.89
128	6.36	6.51	6.78	6.85
512	13.11	13.41	13.89	13.92
1024	17.18	17.55	17.96	17.98
2048	23.37	23.88	24.43	24.43

Dissociation Constants x 10^4

v.	0°	$6^\circ.5$	25°	35°
64	0.323	0.345	0.387	0.393
128	0.338	0.354	0.385	0.394
512	0.387	0.405	0.437	0.440
1024	0.348	0.365	0.384	0.385
2048	0.349	0.366	0.386	0.386

Table XXX.--Metanilic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 12^\circ$	$\mu_v 25^\circ$	$\mu_v 35^\circ$
32	11.60	18.01	26.89	35.01
128	22.90	34.84	51.40	66.89
512	42.76	65.66	95.10	121.1
1024	58.01	87.96	125.8	158.1
2048	76.38	115.1	162.8	203.5

Temperature Coefficients.

v.	0°--12°		12°--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.53	4.61	0.68	3.79	0.81	3.02
128	1.00	4.40	1.28	3.66	1.55	3.01
512	1.91	4.46	2.27	3.45	2.60	2.73
1024	2.50	4.30	2.91	3.31	3.23	2.63
2048	3.23	4.22	3.67	3.19	4.07	2.50

Percentage Dissociation.

v.	$\alpha\ 0^\circ$	$\alpha\ 12^\circ$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
32	5.23	6.32	7.67	8.75
128	10.27	12.23	14.64	16.72
512	19.26	23.04	27.10	30.27
1024	26.13	30.87	35.84	39.53
2048	34.41	40.39	46.37	50.88

Dissociation Constants x 10^4

v.	0°	12°	25°	35°
32	0.90	1.33	1.99	2.62
128	0.89	1.33	1.96	2.62
512	0.90	1.35	1.97	2.57
1024	0.90	1.35	1.96	2.52
2048	0.88	1.34	1.96	2.57

Table XXXI.--Sulphanilic Acid. Molecular Conductivity.

v.	$\mu_v 0^\circ$	$\mu_v 6^\circ.3$	25°	35°
32	21.80	27.25	47.20	60.0
128	40.66	50.89	87.51	110.2
512	74.25	91.33	152.8	188.3
1024	96.40	118.1	193.0	237.0
2048	121.5	148.4	235.2	281.5

Temperature Coefficients.

v.	0°--$6^\circ.3$		$6^\circ.3$--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
32	0.88	4.03	1.07	3.91	1.28	2.71
128	1.62	3.99	1.96	3.85	2.27	2.59
512	2.71	3.65	3.29	3.60	3.55	2.33
1024	3.45	3.57	4.01	3.39	4.40	2.28
2048	4.27	3.52	4.53	3.06	4.63	1.97

Percentage Dissociation

v.	$\alpha\ 0^\circ$	$\alpha\ 6^\circ.3$	$\alpha\ 25^\circ$	$\alpha\ 35^\circ$
32	9.82	10.69	13.45	15.00
128	18.31	19.96	24.93	27.55
512	33.44	35.82	43.52	47.08
1024	43.42	46.33	54.99	58.75
2048	54.71	58.21	67.02	70.37

Dissociation Constants x 10^4

v.	0°	$6^\circ.3$	25°	35°
32	3.34	4.00	6.53	8.27
128	3.20	3.89	6.47	8.19
512	3.28	3.90	6.55	8.18
1024	3.26	3.90	6.56	8.17
2048	3.23	3.96	6.64	8.16

Table XXXII.--O-Amidobenzoic Acid. Molocular Conductivity.

v.	μ 0°	μ 7°5	μ 25°	μ 35°
64	3.071	4.172	7.150	9.001
128	4.642	6.283	10.71	13.39
512	10.90	14.31	23.26	28.96
1024	16.03	20.48	33.53	41.57
2048	21.93	28.30	45.26	55.78

Temperature Coefficients.

v.	0°--7°5		7°5--25°		25°--35°	
	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	0.15	4.78	0.17	4.08	0.19	2.59
128	0.21	4.52	0.25	3.98	0.27	2.57
512	0.45	4.17	0.51	3.58	0.57	2.45
1024	0.65	4.03	0.72	3.46	0.81	2.40
2048	0.85	3.87	0.97	3.43	1.05	2.33

Percentage Dissociation.

v.	α 0°	α 7°5	α 25°	α 35°
64	1.39	1.60	2.05	2.27
128	2.12	2.42	3.07	3.38
512	4.93	5.50	6.67	7.31
1024	7.25	7.87	9.62	10.48
2048	7.88	10.88	13.00	14.07

Dissociation Constants x 10^4

v.	0°	7°5	25°	35°
64	0.0306	0.0408	0.0671	0.0824
128	0.0360	0.0467	0.0761	0.0922
512	0.0499	0.0626	0.0932	0.112
1024	0.0554	0.0658	0.100	0.120
2048	0.0329	0.0649	0.0948	0.113

Table XXXIII.--p-Amidobenzoic Acid. Molecular Conductivity.

v.	μ_v 0°	10°.19	25°	35°
64	3.711	5.136	7.370	8.919
128	5.346	7.527	10.84	12.97
512	12.57	17.39	24.54	29.06
1024	18.87	25.71	35.07	41.31
2048	28.32	37.21	50.13	58.56

Temperature Coefficients.

	0°--10°.19		10°.19--25°		25°--35°	
v.	Cond. units	Per cent	Cond. units	Per cent	Cond. units	Per cent
64	0.14	3.78	0.15	2.92	0.16	2.10
128	0.21	4.00	0.22	2.97	0.21	1.96
512	0.47	3.76	0.48	2.78	0.45	1.84
1024	0.67	3.57	0.63	2.46	0.62	1.79
2048	0.87	3.08	0.87	2.35	0.84	1.68

Percentage Dissociation

v.	α 0°	α 10°.19	α 25°	α 35°
64	1.68	1.87	2.11	2.25
128	2.42	2.75	3.11	3.27
512	5.69	6.34	7.04	7.47
1024	8.54	9.38	10.07	10.42
2048	13.73	13.28	14.38	14.77

Dissociation Constants x 10^4

v.	0°	10°.19	25°	35°
64	0.0448	0.0559	0.0714	0.0790
128	0.0468	0.0606	0.0780	0.0865
512	0.0670	0.0838	0.104	0.118
1024	0.0678	0.0949	0.110	0.119
2048	0.107	0.104	0.118	0.125

Formic and oxalic acids are omitted from the list of those investigated since it was found that they decompose in solution in the presence of the platinized electrodes. This decomposition proceeds so rapidly at high temperatures and dilutions that there is no means of ascertaining when the solutions have come to constant conductivity. With formic acid it was noticed that constant readings could not be obtained within the short space of a few seconds, the conductivity falling off so rapidly. Conversion of the platinum black of the electrodes into platinum white, by heating in the flame of the blast-lamp, lessened but did not entirely eliminate the trouble, so it was therefore deemed best to leave the series of acids incomplete, rather than to give results which could not absolutely be relied upon. The same decomposition took place with gallic acid, but so slowly that good measurements were possible. The solution darkened when in contact with the electrodes, presumably owing to the formation of a small amount of pyrogallic acid, but the conductivity increased very gradually.

Nearly all the acids investigated have temperature coefficients, expressed in percentages, which decrease with rise in temperature and with increase in dilution. This fact is in accord with the theory of hydration of Jones referred to above. From the fact that in solutions of many inorganic salts and mineral acids large percentage temperature coefficients are obtained, these coefficients being greatest in the most dilute solutions, it is clear that the ions of such electrolytes are largely hydrated in aqueous solution. We should expect these large temperature coefficients if the ions are hydrated, since with rise in temperature the hydration would be greatly diminished and the velocity of the ions correspondingly increased; further, that the hydration would be greatest in dilute solutions where the mass action of the water comes

most strongly into play, and thus rise in temperature produce a greater effect. With the organic acids, however, there is probably not such great hydration. The temperature coefficients decrease regularly with dilution and rise in temperature, and are generally small and of the same order of magnitude. The viscosity of the medium is the prime factor which influences increase in conductivity of these acids with rise in temperature.

As exceptions to the statement just made that the organic acids have small temperature coefficients of conductivity, it is noticed that metanilic, sulphanilic, o- and p-aminobenzoic acids have very large percentage temperature coefficients. This result is not due to hydrolysis or hydration, as the greatest effect would be evidenced in the most dilute solutions, whereas the temperature coefficients decrease with dilution. Further mention will be made of this fact.

We turn to a fumdamental part of the problem when we ask--What function of the temperature is the conductivity of these acids? The results for several acids are shown graphically in Figures 1--4, in which conductivities are plotted as ordinates against temperatures as abscissae. It seems to be true generally that the conductivity of these organic acids is a parabolic function of the temperature. The following table (XXXIV) gives value for μ_0 and the constants a and b in the equation

$$\mu = \mu_0 + at + bt^2,$$

where μ is the conductivity at any temperature t, μ_0 the conductivity at 0°; a and b are constants dependent on the nature of the acid. The dilution selected was N/128 and conductivities at 0°, 25° and 35° were used in obtaining the constants.

The last two columns of the table give values for the conductivities observed at the temperature t, and those calculated by the aid of the interpolation formula. The agreement is seen to be satisfactory.

No extended discussion of the percentage dissociation and dissociation constants at any one temperature seems necessary, since the values obtained at 25° are of the same order of magnitude as those obtained by Ostwald⁽¹⁾ in his comprehensive study of the affinity constants of organic acids at 25°. It is interesting to note the dilution at which the second hydrogen of the dibasic acids begins to dissociate. The dissociation constants of malonic, succinic and o-phthalic acids at 25° increase markedly from the dilution V = 1024 to that of V = 2048. It is, therefore, between these dilutions that the acidity of the acids increases. The results with

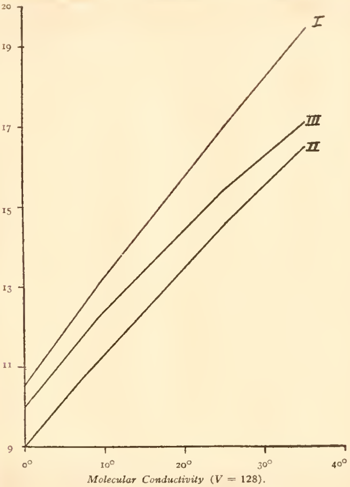

Fig I.—I. Acetic acid; II. Propionic acid; III. Butyric acid.

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(1) Z.physik. Chem., 3, 170 (1889).

those three acids compare very favorably with Ostwald's figures, and the constants for malonic and succinic acids agree satisfactorily with those of Walden(1). It may be seen that this increase in the dissociation constant takes place between the same dilutions at all temperatures. With the stronger dibasic acids such as maleic, fumaric, racemic, citric acids and so on, the increase in dissociation constants comes at greater concentrations although no relation between the dissociation and the dilution at which the second hydrogen dissociates is apparent.

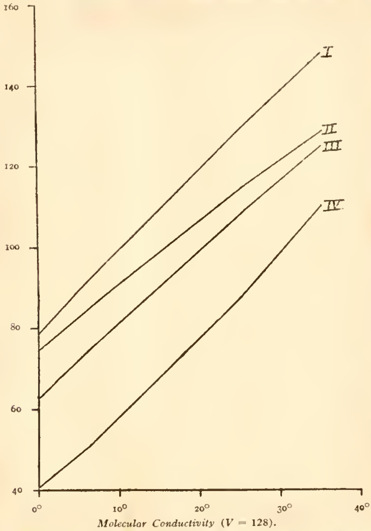

Fig. II.—I, Malonic acid; II, *o*-Phthalic acid; III, Salicylic acid; IV, Sulphanilic a

The increase with dilution in the values of the constants of *o*- and *p*-aminobenzoic acids should be noticed, and is a fact correlated with the change of conductivity of the amino acids with change of temperature. Ostwald(2) assumed that the above increase in dis-

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1. Z. physik. Chem., 7, 433 (1891).
2. Ibid., 3, 261 (1889).

sociation constants is due to the internal salt-forming power of these acids, such salts breaking up on dilution, with a corresponding effect on the conductivity and dissociation. This also explains very well the large percentage temperature coefficients of conductivity, the *increase* in coefficients expressed in units with rise in temperature, and the fact that the conductivity of nearly all the amino acids studied is not a parabolic function of the temperature; for the effect of heat upon the internal salts would be the same as that of dilution, *i.e.* they would fall apart on increasing the temperature, and the free acid would conduct more than the salt itself. Another explanation for the behavior of these amino acids is afforded by a theory advanced by Walker(1) in which he states that amphoteric electrolytes have two dissociation constants, corresponding to dissociation into acid and base; therefore, that the

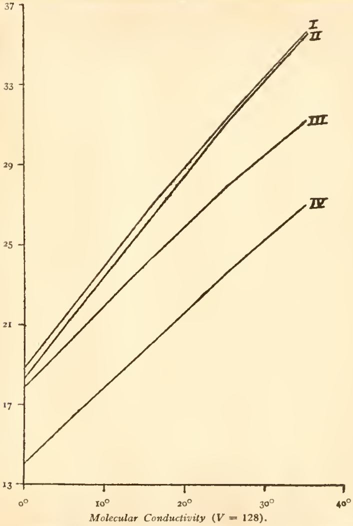

Fig. III.—I. Benzoic acid; II. Succinic acid; III. Phenylacetic acid; IV. Gallic acid.

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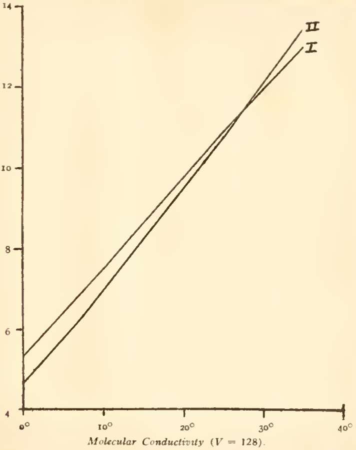
1. Z. physik. Chem., *49*, 82 (1904)

Ostwald "constants" and the dissociation of the amino acids measured in the usual manner are erroneous. He calculated the value for the conductivity of the acids upon his assumptions, and obtained results agreeing with those experimentally obtained by Ostwald and Winkelblech(1).

While inorganic salts and mineral acids all behave in the same way with respect to the change in dissociation with the temperature, the organic acids present a perplexing problem, when an attempt is made to deduce any relation between the change of their dissociation and their chemical constitution. With many of the acids, a maximum in dissociation occurs between 25° and 35°. This statement applies to the following acids,--acetic, propionic, phenylacetic, hippuric, malonic, maleic, fumaric, crotonic, benzoic, m-toluic, cinnamic, salicylic, m-oxybenzoic. The dissociation of succinic, itaconic,



Molecular Conductivity ($V = 128$).

Fig. IV.—I. *p*-Aminobenzoic acid; II. *o*-Aminobenzoic acid.

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1. Z. physik. Chem., 36, 546 (1901).

racemic, pyrotartaric, citric, p-toluic, p-oxybenzoic, gallic, metanilic, sulphanilic, o- and p-aminobenzoic acids, increases from 0° up to 35° without a maximum, but several give indications that one would appear at a slightly higher temperature. The dissociation of the remaining acids,--n- and iso-butyric, mandelic, citraconic, mesaconic, o-toluic, o-phthalic, decreases regularly with rise in temperature from 0°. The most probable dissociation constants of all the acids are given in Table XXXV, from which the above relations become clear.

Table XXXIV.

Acid.	μ_0	a	b	t	$\mu_t$obs.	$\mu_t$calc.
Acetic	10.48	0.287	-0.000856	9°.20	13.04	13.05
Propionic	9.00	0.244	-0.000856	6°.90	10.60	10.64
Butyric	10.00	0.253	-0.00140	9°.40	12.23	12.26
Phenylacetic	17.82	0.460	-0.00217	13°.25	23.39	23.44
Malonic	78.30	2.217	-0.00628	4°.90	88.83	89.00
Succinic	18.24	0.567	-0.00184	5°.70	21.35	21.40
o-Phthalic	74.56	1.752	-0.00571	8°.23	88.32	88.58
Benzoic	18.79	0.556	-0.00207	15°.80	26.93	27.04
Salicylic	62.65	1.919	-0.00411	6°.90	75.59	75.68
Gallic	14.01	0.408	-0.000982	6°.50	16.55	16.62
p-Aminobenzoic	5.35	0.215	-0.000189	10°.19	7.53	7.52

Table XXXV. $K \times 10^4$

Acid.	0°	12°	25°	35°
Acetic	0.175	----	0.184	0.183
Propionic	0.133	----	0.138	0.136
n-Butyric	0.163	----	0.153	0.147
iso-Butyric	0.155	----	0.148	0.142
Phenylacetic	0.540	----	0.545	0.526
Manddlic	4.30	4.29	4.29	4.24
Hippuric	2.22	2.34	2.38	2.33
Malonic	1.48	----	16.3	16.3
Succinic	0.562	----	0.655	0.659
Maleic	143.	145.	154.	151.
Fumaric	9.40	9.72	10.1	10.0
Citraconic	43.6	40.7	38.1	36.3
Mesaconic	8.4	8.4	8.1	7.7
Itaconic	1.24	1.45	1.53	1.55
Crotonic	0.199	0.210	0.215	0.211
Racemic	9.1	9.9	10.8	11.2
Pyrotartaric	79.	79.	87.	88.
Citric	6.85	----	8.66	9.05
Pyromucic	8.7	8.1	7.6	7.0
Benzoic	0.611	----	0.686	0.684
o-Toluic	1.59	1.49	1.37	1.25
m-Toluic	0.515	0.548	0.560	0.554
p-Toluic	0.383	0.410	0.433	0.437
o-Phthalic	13.4	----	12.6	12.2
Cinnamic	0.322	----	0.368	0.367
Salicylic	8.3	----	10.6	10.6
m-Oxybenzoic	0.725	----	0.798	0.789
p-Oxybenzoic	0.251	----	0.285	0.287
Gallic	0.338	----	0.385	0.394
Metanilic	0.90	1.33	1.99	2.62
Sulphanilic	3.28	----	6.55	8.18
o-Aminobenzoic	0.0306	----	0.0671	0.0824
p-Aminobenzoic	0.0448	----	0.0714	0.0790

The results obtained agree generally with those of Eulér(1) and Schaller(2). The former investigator, working at temperatures ranging from 0° to 50°, found that the dissociation of benzoic acid reached a maximum at 35°, while that of *m*-oxybenzoic attained a maximum between 25° and 35°. The dissociation of salicylic acid increased from 0° to 50°, while that of *o*-toluic acid decreased from 0°. Schaller, working at temperatures between 25° and 100°, found maxima in dissociation between 25° and 40° for cinnamic, benzoic,

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1. Z. physik. Chem., *21*, 257 (1896).
2. *Ibid.*, *25*, 497 (1898).

salicylic, m- and p-toluic acids, and observed, as the work of Euler and the results from the present article show, that the dissociation of o-toluic acid decreased with rise in temperature from the lowest temperature at which it was measured.

The hypothesis of Thomson(1) and Nernst(2), which states that solvents having the greatest dissociating power have the largest dielectric constants, explains why the dissociation of inorganic salts and mineral acids decreases with rise in temperature, since it has been shown(3) that the dielectric constant of water decreases also with rise in temperature. Since maxima in dissociation have been found with many of the organic acids, other unknown forces must come into play in such cases. It is particularly interesting to note that such isomers as the toluic acids differ markedly with respect to the change of their dissociation with change in temperature.

Summary of Facts Established.

1. The percentage temperature coefficients of conductivity of the organic acids are generally small and of the same order of magnitude, and decrease with rise in temperature and with increase in dilution. The coefficients expressed in conductivity units decrease with rise in temperature. These facts suggest that the acids are much less hydrated than the mineral acids, for reasons previously given.

2. The percentage coefficients of conductivity of the amino acids are exceptionally large, and the coefficients expressed in conductivity units increase with rise in temperature. The internal salt-forming power of these amphoteric electrolytes explains such behavior.

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1. Phil. Mag., 36, 320 (1894).
2. Z. physik. Chem., 13, 531 (1894).
3. Phil. Mag., 6, 7, 655 (1904).

3. The conductivity of most of the organic acids is a parabolic function of the temperature, as proved by comparing observed values with those calculated from interpolation formulae.

4. Several of the amino acids are again exceptions, and their conductivity is not a parabolic function of the temperature, for the same reasons which explain their large temperature coefficients.

5. There is no general statement possible, concerning the change in dissociation of the organic acids with change in temperature. Maxima occur with several between 25° and 35°, while in other cases maxima are indicated at slightly higher temperatures than those at which measurements were taken. The dissociation of several acids decreases regularly from 0°.

6. Isomeric acids do not behave similarly as regards change in their dissociation.

7. The migration velocities of isomeric ions are identical.

8. The behavior of the organic acids with respect to the change in their dissociation with the temperature is contrary to the hypothesis of Thomson and Nernst, which connects dissociating power and dielectric constants; or at least the influence of some other unknown force is suggested.

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This work will be extended for the organic acids from 35° to 65°, and will also be extended to nonaqueous solvents.

Biographical.

George Frederic White was born in Melrose, Massachuestts, June 15, 1885. His public school education was obtained at Revere and at Malden, Massachusetts. He obtained the degree of Bachelor of Science at the Massachusetts Institute of Technology, Boston, in 1906, and remained at that institution as assistant in chemistry for the two years succeeding. He entered the Johns Hopkins University in 1908 as graduate student in chemistry, receiving a University Scholarship for the academic year 1908-1909, and was appointed Fellow for the year 1909-1910.